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SOLAR COLLECTORS

Technical Progress Report No. 1, September 5, 1978—March 5, 1979

By
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April 27, 1979

Work Performed Under Contract No. EM-78-C-04-5359

Springborn Laboratories, Inc.
Enfield, Connecticut

U.S. Department of Energy

Solar Energy

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For

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ABSTRACT

A broad information search was carried out in four areas: glazings, housing materials, acrylic coatings, etching processes and AR coatings.

An extensive list of all (known) U. S. transparent polymers was developed as well as tables of plastic, ceramic and metallic materials that could conceivably function as a housing. In addition, a compilation was made of commercially available solvent and water-base acrylic coatings for use as a UV protective coating for the glazing.

Eighteen transparent polymers were chosen as possible glazings and twelve materials (plastic and wood) as possible housings and exposed in the Weather-Ometer as tensile bars and for the glazings as disks for optical transmission. These same materials were also exposed on our roof to monitor soiling. A variety of solvent and water-base acrylics were selected as protective coatings and ordered. Two commercial films - Tedlar 20 and Halar 500 - with strong absorption in the UV and two commercial films containing UV absorbers - Tedlar UT and Korad 201R - were laminated by several different processes to four promising glazing materials: polyvinyl fluoride (Tedlar), polymethyl methacrylate (Plexiglass), cross-linked ethylene/vinyl acetate and thermoplastic polyester (Llumar). A variety of etching processes were briefly explored and AR coating studies started on the above four glazing films.

DESCRIPTION OF PROJECT

The project goal is the evaluation of weather-resistant, low-cost, non-glass glazing and housing materials that will have a lifetime of up to twenty years under varying stress and high (300°F) temperature. To accomplish this, an information survey will be made and materials selected. These polymers will then be exposed to accelerated weathering in the Weather-Ometer, and loss of optical, tensile, and other physical properties measured. Critical mechanical, thermal and environmental resistance properties will be examined on polymers having good weather resistance.

The state of development of surface etching processes and solar anti-reflective coatings to reduce surface reflectivity and to increase percent solar transmission of plastics will be investigated. Methods will be investigated for applying anti-reflective coatings to plastics for large-volume production.

Durable coatings and films for UV protection of plastic glazings will be evaluated. Cost studies will be made of collector glazing and housing materials as well as the comparative cost effectiveness of surface etching versus anti-reflective coatings and of UV protective coatings versus building the stabilizer into the polymer molecule.

The overall program is divided into nine technical tasks:

Task 1 - Search the Literature and Contact Suppliers to Select Candidate Materials.

Task 2 - Expose Candidate Glazing and Housing Materials to Accelerated Weathering (UV) and Measure Changes in Optical and Tensile Properties Vs. Time.

Task 3 - Evaluate Critical Properties.

Task 4 - Expose Promising Materials to Accelerated Outdoor Aging on the EMMAQUA and Measure Changes in Optical and Tensile Properties.

Task 5 - Evaluate Durable Coatings or Films for UV Protection of Plastic Glazings.

Task 6 - Investigate Surface Etching Processes.

Task 7 - Evaluate IR-And/Or Anti-Reflective Coatings for Reducing Reflectivity.

Task 8 - Investigate Means for Applying IR And/Or AR Coatings in Large-Volume Production.

Task 9 - Cost Effectiveness.

DISCUSSION

During the first six months of this program work was carried out on the following tasks:

1. Information Search
2. Accelerated UV Exposure
5. UV Protective Coating
6. Etching Processes
7. AR Coatings

TASK 1: INFORMATION SEARCH

There are four broad areas of technology that are being considered in this program: (1) UV-resistant glazing and housing materials; (2) UV protective coatings; (3) surface etching processes; and (4) anti-reflective coatings.

A. Glazings

A nonglass glazing (or housing) and surface coating must withstand many years of outdoor weathering in a terrestrial environment. As new structural materials, plastics offer attractive opportunities for outdoor use. Like most organic materials, however, they are reactive to atmospheric oxygen, moisture, and light. Thus, in extended outdoor use they gradually deteriorate by discoloration, loss of gloss, crazing, chalking, erosion, cracking, embrittlement, and loss of strength and extensibility; eventually they may even crumble away entirely.

The problems of weathering are complicated because of the multiplicity of conditions which may be imposed. Conditions of exposure, the nature of the plastic and its formulation, and the performance requirements are all interrelated and must be considered in choosing a material for an application.

The polymeric glazing (and/or housing) must possess the following characteristics:

a. Rigidity to protect against heavy loads.

b. Clarity (for glazing) maintained over a wide range of exposure conditions.

c. Weather resistance as a combination of ultraviolet, SO_2, and moisture over a long time span without significant loss of clarity or physical properties.

d. Property retention over a wide use/temperature range, from -40 to 300°F.

e. Abrasion resistance (for glazing) to prevent opacification by wind-blown dust.

f. Impact strength against hail or other falling objects.

g. Resistance to hydrolyzing condition, such as high humidity and rain.

h. Ability to withstand stress fatigue arising from temperature cycling and varying physical stress.

i. Ease of maintenance.

j. Low cost.

There are two possible glazing components to the system being considered: (1) the Outer Glazing; and (2) the Inner Glazing. The outer glazing must withstand load stress and weathering plus moderate heat, and it must be abrasion resistant. The inner glazing must be stable to as high as 300°F; its UV resistance requirements are not as great as those for the outer glazing. It could be a thin film of higher use temperature material.

A wide-ranging information search has been carried out to select nonglass materials for collector glazings and housings. Sources have included the literature, DOE contractor reports, JPL (photovoltaic) contractor reports, Springborn Laboratories, Inc. (SLI) work on the JPL solar cell encapsulation contract, and telephone calls to a variety of material manufacturers.

All commercially available transparent polymers were surveyed and tabulated (Tables 1A-1D). The four survey tables were constructed according to price range, the ranges being: under $0.50 per pound (1A), $0.50 to $1.00 per pound (1B), $1.00 to $4.00 per pound (1C), and polymers costing in excess of $4.00 per pound (1D). The tables are set up to include in the first section a description of the polymer - i.e., its generic chemical type, at least one of its trade names, and the manufacturer. A given polymer is often available through many other producers, but for the sake of convenience only one has been listed.

The polymers surveyed encompassed a great variation in physical properties and chemistry and included such materials as the following: polyvinyl chloride, polystyrene, polyethylene, polyesters, ionomer, polyimides, cellulosics, urethanes, silicones, etc.

In the central portion of the table is a column showing the survival prognosis; this involves the survival span in years of unprotected materials. In the next column is shown an upgrading potential in years of completely protected polymers. By complete protection we imply a high level of an internal UV additive synergistic system and a film or coating containing a high level of UV absorber to screen out the impinging UV light. All of these figures are educated opinions, based on experience with related materials since this type of specific information is rarely available. The years predicted for the virgin polymer are given in ranges and those for the protected polymer as Fair (F) or Good (G) at 10 and 20 years of lifetime.

Among the 50 percent of the surveyed materials which fall within the cost range of $0.01 to $0.05 per square foot, no transparent material which could survive unprotected for 20 years outdoors has been identified. Currently existing weatherable fluorocarbon and silicone products are high-priced ($0.44 - 2.00/ft.^{2}), but acrylics are more moderately priced and are viable candidates.

B. Housings

Tables 2A, B, C, and D list respectively plastic, metal and ceramic materials that may be suitable for housings. Each table lists the manufacturer, the material, grade, physical form, flexural modulus, density, cost/lb., cost/ft^2 and the volume cost.

As the tables indicate, the study was divided into sections according to the class of materials under investigation. For some composites, flexural modulus values could not be found since the value changes with variations in design.

Plastic materials were the first considered - because of their fabrication versatility, relatively low cost, high availability, and the possibility of their being compounded with inexpensive fillers to further reduce the cost (Table 2A).

The cost effectiveness is basically a ratio of the stiffness (flex modulus) to the material cost. Fillers and fibers added to improve the rigidity also raise the density, however, and consequently many of the high-strength materials are less cost effective because of the increase in cost per unit volume.

Resin-reinforced structural laminates such as epoxy and polyester preimpregnated glass matt were much more expensive than a paper-based phenolic laminate. It was assumed that the stiffness-to-weight ratio of structural foam plastics would place them at an economic advantage, but actual costing found them to be competitively priced with many filled resins. The least expensive plastics in the table are filled polypropylenes.

A brief survey of some of the more widely used metal construction products (Table 2B) indicates that they may be competitive with plastics. The use of metals may also incur an additional fabrication cost if special design is required, as opposed to plastics that may be molded in a one-step operation.

Ceramic-based substrates were also briefly considered (Table 2C), and costed out at lower prices than either plastics or metals. A drawback, however, is that the densities of these materials are so high, that they would undoubtedly require expensive support. Glass reinforced gypsum board would not endure outdoor weathering for long because of its high water sensitivity. The cost of upgrading would probably be high. Additionally, the elastic limit in this and other ceramic materials is very low. Small deflections in the panel would cause cracking and fatigue, leading to catastrophic failure.

Elasticized cement is a weatherable compound, however, and has a degree of flexibility not found in other mineral products. Latex-modified cement is estimated at $0.40 to $0.50 per square foot in 1/4 inch thicknesses. The load-bearing capacity is not presently known, and the cost also needs further investigation.

Table 2D lists some of the wood product substrates investigated to date. This class represents the lowest cost structural materials at approximately three to four times less than the cost of the least expensive plastic compounds surveyed.

A disadvantage to plywood, however, is that it is manufactured in only certain standard thicknesses and would require retooling to produce special grades. This difficulty is overcome with the use of particle boards such as hardboard, chip board, and flake board - all of which are made by an extrusion and/or compression-molding type of process in which the thickness may be varied.

The lowest-cost particle board discovered so far is a 3/8-inch thick wood chip/phenolic binder composite (Roadman Company) which is marketed as having a flexural modulus of 500,000 psi and a cost of $0.16 per square foot. Unfortunately, this product is not weatherable in its commercial form.

As may be seen in Table 2D, the other types of fiber or particle board are similarly priced. The results of the wood products survey are highly encouraging, and continuation into a more extensive survey is desirable.

Paper based materials are only just coming under investigation and three products of interest (not tabulated) have been identified. A structural paneling material known as "Homasote" is available in 0.5-inch thickness at $0.14 per square foot. This compound is prepared from waste paper and has a flexural modulus of 80,000 psi, which provides adequate deflection resistance for its thickness. Another interesting product is a weather-proofed pressed paper board panel manufactured by Mead Paperboard Products, Inc. under the trade name of "Pan-L" board. This panel material has a modulus of 615,000 psi. Mead claims this panel board has endured 17 years of outdoor weathering in Wisconsin. Lastly, contacts have been made with Hexcel Corporation, manufacturers of a Kraft paper honeycomb-composite structural panel costing approximately $0.09 per square foot. This product is made for internal or protected use only, however, weatherable grades are currently under development.

Weatherability is also a factor requiring consideration. Wood products again have importance in this area due to the advantages presented by:

- History of actual outdoor aging in a wide variety of climates.
- Known preservation techniques (such as Koppers "Osmose K-33").
- A known technology of protective marine paints and coatings.
- The ability to formulate binders for maximum hydrolytic and adhesive stability.

C. Coatings

One method of protecting a substrate against ultraviolet light degradation lies in the use of a thin coating containing relatively high concentrations of UV absorber. The weather resistance of the coating must be sufficient to protect the thick layer underneath. This can most likely be produced by compounding a high concentration of ultraviolet absorber into the thin coating, sufficient to stop ultraviolet energy before it enters the thick encapsulant underneath. In general, substituted o-hydroxy benzophenones and benzotriazoles are the best primary ultraviolet absorbers, and may often be synergized by organo-nickel and other additives.

In addition, it would be highly desirable that the thin coating be based on a polymer which is itself stable to ultraviolet, thus eliminating the need for stabilizing it, and avoiding the problem of surface degradation of the thin coating itself. These thin coatings might best be based on fluorocarbons, acrylics, or silicones. The acrylics are much more reasonable in price than silicones or fluorocarbons, therefore, in this initial survey only acrylic coatings were considered.

Fortunately there exists an enormous number of acrylic products available in brushable and sprayable forms such as latex (water-emulsion based) and solution grades (solvent based) that may serve as UV screening vehicles. Rohm & Haas Company, a manufacturer of acrylics, has exposed coatings to more than twelve years of outdoor weathering without any visible evidence of deterioration(1). Experiments at Springborn Laboratories with acrylic coatings show equally successful performance.

Solvent-based acrylic coatings are polymers formulated especially for film-forming ability and solvent compatibility. Grades vary according to solvent composition, percent solids, surface hardness, and glass transition temperature. Table 3A shows the manufacturer, percent solids, type coating, curing agent (if applicable) and costs.

Since polymers with overly high molecular weights provide solutions of low solids content and unworkably high viscosities, an alternate solution is to introduce crosslinking to obtain improved properties. The advantages offered over thermoplastics in this approach are:

- Improved toughness and hardness.
- Resistance to softening at higher temperatures.
- Better resistance to solvents and moisture.
- Lower solution viscosity and higher application solids.
- Better compatibility with substrate materials.

(1) Rohm & Haas, "Thermoplastic Acrylics-Exposure Series 57YY" Memo 51-1243; May 14, 1969; Quoted by Permission.

Solvent-based thermoset resins may be applied by conventional coating methods, dried, and cured through an oven cycle to produce the ultimate properties.

Latex-based coatings may be essential to avoid solvent attack on the organic glazing (Table 3B).

Emulsion, or latex, polymers consist of discrete spherical particles of high molecular weight polymer dispersed in water (Table 3B). Since the polymer particles are separate from the continuous aqueous phase, the viscosity of the dispersion is relatively independent of the polymer's molecular weight. Consequently, molecular weight can be raised to high levels to take advantage of the resulting improvement in performance properties.

Viscosity remains conveniently low and permits wide formulating latitude. Because of their molecular weight advantage emulsion polymers exhibit good toughness, chemical and water resistance, and outdoor durability characteristics. Also, they allow the highest application solids (up to 70 percent).

D. Surface Etching

To allow the maximum percentage of solar energy to pass through to the collector, the plastic glazing must have minimum reflectivity. One way of achieving this is through etching of the plastic surface.

The following represents some of the plastic surface etching methods that have been explored in the past; although the goal was to improve adhesion:

a. Sulfuric acid/dichromate[1]

b. Argon ions[2]

c. Aqueous KOH[3]

d. Sodium dodecylbenzenesulfonate/trisodium phosphate/ sodium hypochlorite[4]

e. Sodium hydroxide/organic solvent/wetting agent[5]

f. Sodium in liquid ammonia or naphthalene-THF[6]

g. Glow discharge[7]

h. Aqueous hydrazine[8]

i. Pyridine/dimethyl sulfoxide/tetraethyl-ammonium hydroxide[9]

j. N,N-dialkylamide or pyridine[10]

k. Naphthalene-sodium-tetrahydrofuran complex[11]

l. Hydrazine compounds/alkyl hydroxy compounds/polar solvents[12]

Honeywell, Inc.[(13)] examined the use of sodium-naphthalene-tetrahydrofuran, acetophenone and cyclohexanone to etch Tedlar to improve transmission. The Tedlar was to be used as a collector glazing. Only acetophenone improved transmission, by 2-3%, of a few of the seven Tedlar sheets examined.

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3. V. I. Astrina, et al - Plast. Massy (9), 47-8 (1975).

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5. French Patent 2,199,012.

6. W. M. Riggs, et al - J. Electron Spectrosc. Relat. Phenon. 5, 477-60 (1974).

7. Z. Pelgbauer, et al - J. Polym. Sci., Polym. Phys. Ed. 12, (10), 2173-6 (1974).

8. U. S. Patent 3,820,994.

9. U. S. Patent 3,871,930.

10. Japanese 74-036,837.

11. Japanese 74-014, 136.

12. Japanese 74-111,975.

13. J. H. Lin, et al, Honeywell, Inc., NTIS Report PB 252,383

TASK 2: ACCELERATED UV EXPOSURE OF GLAZING AND HOUSING MATERIALS

The two transparent glazing materials have different requirements. The inner glazing must withstand 300°F but does not have to withstand a load or be as resistant to UV, since it is screened by the outer glazing. The outer glazing must resist stress and weather and be abrasion resistant, but its temperature requirements are much lower.

The housing materials must resist 300°F and carry a load. However, weather-resistant requirements are simple in that the housing material can be opaque. Carbon black or zinc oxide pigment can be used to provide UV resistance.

All materials must be capable of being mass-produced and must be low in cost.

A wide variety of glazing materials are under exposure in the carbon arc Weather-Ometer, including:

- Thermoplastic polyesters (1-5)

  The surface of Nos. 1, 3 and 4 is impregnated with a UV absorber.

- Thermoset Fiberglass-Reinforced polyesters (6-8)

- Fluorocarbons (9-13)

  The Tedlar film is a new UV resistant grade for solar applications.

- Polycarbonate (14, 15)

  Tuffak has an abrasion resistant coating.

- Cellulose Ester (16)

  Cellulose acetate butyrate has long been used in outdoor signs.

- Acrylic (17)

  This class is represented by an acrylic homopolymer.

- Crosslinked Polyolefin (18)

  Crosslinked ethylene/vinyl acetate is elastomeric and tough.

They were chosen on the basis of weather resistance or wide outdoor industrial usage (solar or otherwise). Polycarbonate was included for the latter reason but it is basically not UV stable.

All films and sheets were used as received from the manufacturer except for Plexiglass V811 which was compression molded into sheet in this laboratory.

Table 5 reveals possible housing materials that have been put on exposure in the Weather-Ometer. Classes of compounds include:

- Wood composites (1 and 2)
- Fiberglass reinforced polyester (3 and 14)
- Peroxide crosslinked, filled HDPE (4 and 5)
- Thermoset compounds (6 and 7)
- Glass or talc filled thermoplastics (8 and 10)
- Thermoplastic foams (9 and 13)
- PVC compounds (11 and 12)

The two PVC pipe compounds were compression molded from pellets. The peroxide-containing, carbon black and Burgess KE clay filled, compounds were compounded on our two-roll mill, and cured while compression molding into sheets. All other sheets were used as received.

Many more glazing and housing materials are included in this study than were called for in the contract to allow for failure, as well as to provide thorough coverage of possible materials.

The procedure and formulation used to prepare the peroxide crosslinked carbon black in clay formulations follows:

Carbon Black Formulation

Cabot Sterling NSx76 Carbon Black	16.5%
Phillips-Marlex 5003 High Density Polyethylene (HDPE)	82.3%
Lupersol 101 Peroxide	1.2%

Clay Formulation

Burgess KE Vinyl Silane Coated Clay	16.5%
Marlex 5003 HDPE	82.3%
Lupersol 101	1.2%

The carbon black and clay were oven dried at 60°C overnight. The HDPE was fluxed on a two-roll mill and the black or clay milled in; finally, at the end of the milling cycle the peroxide is blended in. Compression mold curing was carried out at 325°F for 20 minutes.

The following tests will be run after each exposure time, whenever possible:

- Ultimate tensile strength
- Ultimate elongation
- Elongation at Yield
- Tensile Modulus
- Qualitative color formation and other visual changes
- Total integrated solar transmittance

In addition, the tendency of a plastic to accumulate dust, soot, debris, etc., is being assessed by exposing glazing sheets on our roof. Light transmission will be measured at 120 and 240 days, before and after washing the surface at each set of readings. This will give us the following information:

(1) Effect of outdoor weathering on optical transmission.

(2) Effect of dirt accumulation on optical transmission.

(3) Tendency of a plastic to retain dirt.

Separate sets of tensile bars and one inch diameter samples (for optical testing) are on exposure for 120, 240 and 480 days in the Atlas G23 Weather-Ometer. This device exposes a revolving rack of test specimens to the light of a three-filament carbon arc lamp combined with intermittent water spray.

TASK 5: UV PROTECTIVE COATINGS AND FILMS

The polymeric glazing must have a lifetime of at least 10-20 years.

Of all commercial, organic polymers only fluorocarbons, silicones and, to a lesser extent, acrylics have appreciable UV stability. All other polymers, including some acrylics, need protection against UV.

Three methods are being investigated to provide this protection.

A. UV Stable Acrylic Coatings with High UV Absorber Concentration*

- Service Coatings
- Red Spot
- Valspar
- Rohm & Haas
- Conchem Co.
- Goodrich
- Ashland
- MR Plastics
- Monsanto
- BASF
- Union Carbide
- Polyvinyl Chemicals
- Johnson Wax
- Celanese
- Nation Starch
- Staley Chemical
- Spencer Kellog
- Air Products

Those coatings which the companies recommend as having long UV life will be examined for coating qualities. The most promising coatings will be formulated with UV absorbers and examined as protective coatings.

Special attention will be paid to the possibility that the solvent in solvent-based coatings may attack the polymer glazing.

B. Film with UV Absorbing Characteristics and Commercial Films Containing UV Absorbers

Two unmodified polymer films which absorb strongly in the UV but are themselves stable to UV are being investigated. The properties of these films are:

Properties	Tedlar 20[(1)]	Halar 500[(2)]
Percent UV transmittance before aging	13	36
Percent elongation retained after 120-day exposure in -		
Weather-Ometer, 55°C	100	135
RS-4 Sunlamp, 55°C	141	131

(1) Polyvinyl Fluoride
(2) Ethylene/Chlorotrifluoroethylene

*The following companies have been contacted to obtain solvent and/or latex acrylic coatings.

There are also two commercial films on the market which contain UV absorbers. These are Tedlar UT, a fluorocarbon film made by DuPont and Korad 201R, an acrylic film made by XCEL Corp. These films were laminated to the four glazing films shown below:

Tedlar 400XRB 160SE (Polyvinyl Fluoride)
Plexiglass V-811 (Acrylic Homopolymer)
Crosslinked Ethylene/Vinyl Acetate Copolymer
Llumar (Thermoplastic Polyester)

The glazings were chosen on the basis of being most promising plus having four different chemical structures. Lamination was carried out in a press with heat alone, peroxide plus heat and GE and Dow Corning adhesives.

The top box in each section of Table 6A is lamination by heat alone; the bottom section is with peroxide. In Table 6B, the adhesives used are GE SS-4179 and Dow Corning 90% Z6030/10% Z6020. Those laminates with sufficient adhesion will be immersed for one week in water to assess wet bond strength. If still promising, they will be exposed in the Weather-Ometer.

TASK 6: ETCHING PROCESSES

The usual technique on silicon or glass surfaces to decrease reflectance and increase transmission is the use of AR coatings. An alternate method used on glass has been chemical etching.

In our work a wide variety of potential chemical etchants have been examined on four transparent plastics: peroxide crosslinked ethylene/vinyl acetate copolymer (Elvax 150 from DuPont), polymethylmethacrylate (Rohm & Haas' Plexiglass V-811), thermoplastic polyester (Llumar - a UV absorber impregnated material from Martin Processing, Inc., Martinsville, Va., and polyvinyl fluoride (Tedlar XRB160SE from DuPont). These four were chosen because they are four widely varying chemical structures - polyolefin, acrylic, thermoplastic polyester and a fluorocarbon - with potential as glazings.

The polymer sheets were treated, as shown in Tables 7A through 7D, and 75° gloss (as a guide to reflectance), was measured on a gloss meter (Gardner Portable 75° Glossmeter, Gardner Labs, Bethesda, Md.). In many experiments gloss was reduced. However, to check the validity of these gloss readings reflectance and transmission were run on specific cases.

Table 7E compares the results of gloss, reflectance and transmission measurements on Llumar polyester, EVA and V-811 acrylic.

With EVA, gloss was reduced considerably by room temperature immersion in toluene, but transmission was decreased somewhat and reflectance remained unchanged. The acrylic treatment (29% sodium hydroxide) also decreased gloss and, reflectance was decreased from 8 to 6%, but transmission remained unchanged.

Two conclusions are apparent:

(1) Gloss is not a valid method of measurement.

(2) None of the treatments so far examined is effective.

Work will continue.

TASK 7: AR COATINGS

Anti-reflective coatings have had a long history of use on glass and are now being applied to plastics to decrease reflectance losses. The ideal condition is the maximization of solar transmittance while retaining infrared reflection characteristics. A wide variety of materials have been used as anti-reflective coatings - including magnesium fluoride, cerium oxide, silicon monoxide, zinc sulfide, tin oxide, etc. These coatings are capable of reducing the approximate 4 percent reflectance at each surface to as low as 1/2 percent, on glass.

The coatings are applied to glass by vacuum evaporation over one to two hours at 300°C. Under these conditions a tough coating is formed. By necessity these coatings must be applied to plastics at a much lower temperature, producing a coating which may be less durable.

The anti-reflective coating must have a refractive index between that of air and the plastic, i.e., between 1.0 and approximately 1.5. Magnesium fluoride is one such material.

Sheets of the following are being coated with a single layer of magnesium fluoride and a multiple layer coating, both at 45° and 90° angles.

- 5 mil Llumar (thermoplastic polyester)
- 35 mil crosslinked ethylene/vinyl acetate copolymer
- 4 mil Tedlar 400XRB 160SE (polyvinyl fluoride)
- 40 mil Plexiglass V-811 (acrylic)

If transmission is increased, the coated films will be exposed in the Weather-Ometer.

FUTURE WORK

Weather-Ometer and outdoor (for soiling on glazing) exposure of glazing and housing materials will continue. Samples exposed four months will be evaluated for tensile and transmission (where applicable) properties. Etching processes and AR coatings for glazings will be explored in greater depth.

Film laminates of the best UV protective films over the four glazing materials selected will be made and put on exposure in the Weather-Ometer. Laboratory work will begin to screen acrylic coatings and to develop protective systems of acrylic coatings with UV absorbers.

<u>TABLE 1A</u>

Transparent Plastics Survey
Materials Under 50 Cents/Pound

Generic Type	Trade Name	Manufacturer	Survival Prognosis: Max. Span of Years to Failure (a,b)	Upgrading Potential in Years (a,c)	
				10	20
Hydrocarbon polymers	Polyvol G100	Velsicol	< 1	F	P
Hydrocarbon polymers	X 125, 685	Neville	< 1	F	P
Polyvinyl chloride (PVC)	Geon 103	Goodrich	1-5	G	F
Polystyrene	Cosden 500	Cosden Oil	1-5	F-G	P-F
Polypropylene	Profax 6523	Hercules	< 1	F-G	P-F
Poly-α-methyl styrene	Resin 18	AMOCO	1-5	F	P
High-density polyethylene	Dow 75731	Dow	1-5	G	F
Low-density polyethylene	DYNH	UCC	1-5	G	F
Ethylene/vinyl acetate	EVA 3185	Du Pont	1-5	G	F
Plasticized PVC copolymer	Numerous		1-5	G	F
Ethylene/ethyl acrylate	DPD 6169	UCC	1-5	G	F
Isophthalic polyester	Aropol	Ashland	1-5	G	F
Styrene/acrylonitrile	Lustran	Monsanto	1-5	F	P
Styrene/butadiene	Kraton	Shell	< 1	F	P
Propylene/ethylene	Polyallomer 5021E	Eastman	< 1	F	P
Neopentyl glycol polyest.	Cargill 5446	Cargill	1-5	G	F
Ethylene propylene rubber	Nordel	Du Pont	1-5	G	F
Chlorinated polyethylene	CPE	Dow	1-5	F-G	P-F
Polybutylene	Witron	Witco	< 1	F	P
PVC Plastisol copolymer	Numerous		1-5	G	F

(a) Springborn Laboratories educated opinion

(b) No UV absorber

(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber.

Code: G = Good; F = Fair; P = Poor

TABLE 1B

Transparent Plastics Survey
Materials Costing 50 Cents to $1.00/Pound

Generic Type	Trade Name	Manufacturer	Survival Prognosis: Max. Span of Years to Failure [a,b]	Upgrading Potential in Years [a,c]	
				10	20
Unfilled cast phenolic	Gen-El	G.E.	< 1	P	P
Modified polyethylene terephthalate	Kodar PETG	Eastman	1-5	G	F
Clear acrylonitrile/butadiene/styrene (AMBS)	Cycolac CIT	Marbon	1-5	F-G	P-F
Ethylene/acrylic acid	EAA 435	Dow	1-5	F-G	F-P
Acrylic multipolymer	XT 250	Am.Cyanamid	1-5	F	P
Polybutadiene	Poly BD	ARCO	< 1	P	P
Ionomer	Surlyn 1707	Du Pont	< 1	F-G	F-P
Acrylonitrile/rubber/multipolymer	Barex	SOHIO	1-5	F	P
Melamine formaldehyde [d]	Cymel	Am.Cyanamid	5-10	G	F-G
Polybutadiene telomer	-	Lithium Corp.	< 1	P	P
Polyvinyl alcohol	Gelvatol	Monsanto	1-5	F	P
Cellulose propionate	Tenite	Eastman	1-5	G	F
Cellulose acetate buryrate	Tenite 479	Eastman	4-5	G	F
Cellulose acetate	Tenite	Eastman	1-5	G	F
Chlorosulfonated polyethylene	Hypalon	Du Pont	1-5	G	F
Thermoplastic polyester	Vitel	Goodyear	1-5	G	F
Vinyl chloride/vinyl acetate	VYHH	UCC	1-5	F	P

(a) Springborn Laboratories educated opinion

(b) No UV absorber

(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber

(d) Not sold unfilled; data are on cellulose-filled product.

...Continued

TABLE 1B (Continued - 2)

Generic Type	Trade Name	Manufacturer	Survival Prognosis: Max. Span of Years to Failure	Upgrading Potential in Years	
				10	20
Linear epoxy	Phenoxy	UCC	1	F-G	F
• Hot Melts Ethylene/vinyl acetate	Bostik 4364	Bostik(USM)	1-5	G	F
Polyamide	Versalon 1112 Milvex 1000	General Mills	1	F	P
Acrylic (solid materials)	329-002 68-42	Daubert Williamson	8-10 8-10	G G	G G
• Acrylics Copolymer Homopolymer	Plexiglas DR100 Plexiglas V811	Rohm & Haas Rohm & Haas	5-10 16-20	G G	G G
MMA*/styrene (60% MMA) MMA /styrene (85% MMA)	P205 P301	Richardson Richardson	5-10 8-10	G G	G G

* MMA = Methyl methacrylate

TABLE 1C

Transparent Plastics Survey
Materials Costing $1.00 to $4.00/Pound

Generic Type	Trade Name	Manufacturer	Survival Prognosis: Max. Span of Years to Failure [a,b]	Upgrading Potential in Years [a,c]	
				10	20
Epoxy urethane	Isochem UE5	Isochem	1	F	P
Castable urethane	System 30	Castor	1	F	P
Nylon copolymer	Versalon	General Mills	1	F	P
Poly(4-methyl pentene)	TPX RT18	ICI	1	F	P
Polyvinyl butyral	Butvar	Monsanto	1-5	G	F
Polycarbonate (stabilized)	Lexan 123-111	G.E.	10-20	G	G
Polycarbonate (hydrogenated)	C-4	UCC	4-5	G	F
MMA casting resin	Tame 500	B.F. Goodrich	8-10	G	G
Nylon 6/12	Capron	Allied Chem.	1-5	F	P
Polyaryl sulfone	Udel 1700	UCC	1-5	F	P
Polyglycol epoxy	DER 732	Dow	1-5	F	P
Epoxy casting resin	Eccogel 1265 Stycast 1264	Emerson & Cummings	1-5	F	P
Polysulfone	Radel P Natural	UCC	1	F	P
Diethylene glycol diallyl carbonate	CR-39	PPG	5	G	F

(a) Springborn Laboratories educated opinion

(b) No UV absorber

(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber

TABLE 1D

Transparent Plastics Survey
Materials Costing More Than $4.00/Pound

Generic Type	Trade Name	Manufacturer	Survival Prognosis: Max. Span of Years to Failure [(a,b)]	Upgrading Potential in Years [(a,c)]	
				10	20
Silicone gel	63-6527	Dow	8-10	G	G
Cycloaliphatic epoxy	ERL 4221	UCC	4-5	G	F
Polyvinylidene fluoride	Kynar 460	Pennwalt	>20	G	G
Perfluoroethylene propylene	FEP 100	Du Pont	>20	G	G
Ethylene/chlorotrifluoroethylene	Halar 500	Allied Chem.	>20	G	G
Ethylene/tetrafluoroethylene	Tefzel 280	Du Pont	16-20	G	G
Hexafluoropropylene vinylidene fluoride	Viton AHV	Du Pont	4-5	G	F
Silicone	Sylgard 184	Dow	10-20	G	G
Silicone	RTV 615	G.E.	10-20	G	G
Perfluoroalkoxy	PFA 9705	Du Pont	> 20	G	G
Silicone "glass resin"	Resin 650	Owens-Illinois	16-20	G	G
Chlorotrifluoroethylene	Resin 81	3M	> 20	G	G
Chlorotrifluoroethylene/vinylidene fluoride	Kel-F 800	3M	1-5	G	F
Polyvinyl fluoride film	Tedlar 20	Du Pont	10-20	G	G

(a) Springborn Laboratories educated opinion

(b) No UV absorber

(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber.

TABLE 2A

Plastic Based Substrate Materials

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10^5)		Density (g/cc)	Price		Avg. Cost/ Volume ($/in^3)
				Length-wise	Cross-wise		$/Lb	$/Ft^2	
LNP	HDPE Fiberglass reinforced								
	20% Fiberglass	FF-1004	Pellet	6.0		1.10	0.61	-	0.0242
	40% Fiberglass	FF-1008	Pellet	11.0		1.28	0.69	-	0.0318
LNP	HDPE Glass bead filled								
	20% Glass	FB-1004	Pellet	3.4		1.10	0.61	-	0.0242
	40% Glass	FB-1008	Pellet	3.9		1.28	0.69	-	0.0318
Primex	Acrylic Honeycomb	Prime-Cor-X-Lucite	4mm Sheet	(a)		0.28 lb/ft^3	-	0.60	0.0265
Voltek	Polyethylene foam	R300	1" Sheet	(a)		2.4-4.0 lb/ft^3	-	1.50	0.0104
Norfield	Polycarbonate Honeycomb	NorCore	1" Sheet	(a)			-	0.85	0.0059
Norfield	Impact Styrene Honeycomb	NorCore	1" Sheet	(a)			-	0.55	0.0038
Rohm & Haas	Acrylic	V-811	Pellet	3.0		1.2	1.42	-	0.0391
General Electric	Polycarbonate	Lexan 123	Pellet	3.2		1.2	1.84	-	0.077
Monsanto	Polystyrene	Lustran	Pellet	2.1		1.08	0.38	-	0.0142

(a) These are structural materials that demonstrate only apparent modulus.

TABLE 2A (Continued - 2)

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10^5)		Density (g/cc)	Price		Avg.Cost/ Volume ($\$/in^3$)
				Length-wise	Cross-wise		\$/Lb	\$/Ft^2	
Numerous	Polyurethane foam, rigid	-	Foam	0.5		0.32	0.77	-	0.0089
Rohm & Haas	Polycarbonate Honeycomb	Tuffak		3.2(a)		0.16	4.40	-	0.0252
Synthane Taylor	Paper-based phenolic laminate	X, 1/16"	Sheet	18.0	13.0	1.36	1.00	0.46	0.0490
Synthane Taylor	Fabric-based phenolic laminate	C, 1/16"	Sheet	10.0	9.0	1.36	2.07	0.94	0.1016
Synthane Taylor	Glass-reinforced melamine laminate	G-9	Sheet	25.0	20.0	1.90	2.90	-	0.1988
Synthane Taylor	Glass-reinforced epoxy laminate	G-10	Sheet	27.0	22.0	1.80	3.07	-	0.1994
Synthane Taylor	Glass-reinforced epoxy laminate	FB-400	Sheet	27.0	22.0	1.80	2.10	-	0.1364
Kalwal	Polyester Fiberglas laminate	1.16" 1/8"	Sheet	10.0		1.45	- -	0.52 0.85	0.0472
Arco Polymer	Glass-reinforced styrene-maleic copolymer	Dylark 238 F20	Compound	7.2	4.1	1.22	0.46	-	0.0202
Arco Polymer	Styrene-maleic copolymer	Dylark 238	Compound	4.6		1.08	0.35	-	0.0136

TABLE 2A (Continued - 3)

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10^5)		Density (g/cc)	Price		Avg.Cost/ Volume ($/in^3)
				Length-wise	Cross-wise		$/Lb	$/Ft^2	
Arco Polymer	Structural foam, by Carbide Process	Dylark 238 F20, 1/4"	Sheet	5.3		0.8	-	0.64	0.0177
Fiberite	BMC (Bulk Molding Compound)	S-660B	Compound	15.0		1.8	0.65	-	0.0422
Fiberite	B-stage dry polyester molding compound	S-6414	Compound	15.0		1.8	1.30	-	0.0844
Fiberite	Short glass fiber reinforced phenolic molding compound	FM-4007	Compound	25.0		1.75	0.85	-	0.0536
ICC Primex	High-impact polystyrene		Sheet	2.7		1.04	0.45	-	0.0168
American Hoechst	Rigid vinyl		Sheet	4.7		1.4	2.00	-	0.1010
Hercules	Polypropylene homo-polymer with 40% talc	65F4-4	Compound	5.5		1.22	0.32	-	0.0140
Hercules	Polypropylene homo-polymer with 40% $CaCO_3$	65F5-4	Compound	4.0		1.22	0.31	-	0.0136
Hercules	Polypropylene copoly-mer with 40% talc	75F4-4	Compound	5.0		1.22	0.33	-	0.0145
Hercules	Polypropylene copoly-mer with 40% $CaCO_3$	75F5-4	Compound	4.0		1.22	0.34	-	0.0149

TABLE 2A (Continued - 4)

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10^5)		Density (g/cc)	Price		Avg. Cost/ Volume ($\$/in^3$)
				Length-wise	Cross-wise		$/Lb	$\$/Ft^2$	
Hercules	Polypropylene structural foam	Med. impact copolymer 1/4"	Sheet	1.07		0.67	0.65	-	0.0157
Hercules	Polypropylene structural foam - 30% coupled Fiberglas	PC-072	1/4" Sheet	4.33		0.75	0.80	-	0.0216
Goodrich	Rigid PVC pipe compound	85781	Compound	Tensile Modulus 4.2		1.40	0.31	-	0.0156
Goodrich	Rigid PVC pipe compound	85707	Compound	Tensile Modulus 4.6		1.40	0.30	-	0.0151
Goodrich	PVC pipe compound	3007	Compound	4.26		1.55	0.79	-	0.0441
Premix	Polyester sheet molding compound	1222	Compound	15.0		1.85	0.61	-	0.0407
Ferro	Epoxy prepreg	E-293	10-mil Sheet	33.0		1.80	-	0.34	0.2361
Mastic (Valley Building Products)	Vinyl siding, 0.046" thick, for home exteriors		Sheet	4.0		1.46	-	0.45	0.0679

TABLE 2B

Metals

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10^5)		Density	Price		Avg. Cost/ Volume ($\$/in^3$)
				Length-wise	Cross-wise	(g/cc)	$/Lb	$\$/Ft^2$	
Armco	Galvanized steel	Roofing stock, 80-gage	Coil: 25-mil 50-mil 150-mil	300		7.8	- - -	0.21 0.42 1.26	0.058
Republic	Aluminum-coated steel	26-gage 1.5-mil coat	Sheet: 25-mil 40-mil	300 300		7.8 7.8	- -	0.25 0.60	0.104
Republic	Painted steel	26-gage	40-mil Sheet	300		7.8	-	0.60	0.104
Republic	PVC-coated steel	26-gage	40-mil Sheet	300		7.8	-	0.80	0.138
Alcan	Aluminum	5052H32; H34	25-mil Sheet	100		2.6	0.84	-	0.079
Hamden	Aluminum	11H14; 5052H14	20-mil Sheet	100		2.6	0.85	-	0.079
Alcan	Anodized aluminum	Anodized film: 1-mil 1.5-mil	Coil: 25-mil 25-mil	100		2.6	0.95 1.05	-	0.094
Numerous	Stainless steel	316	Sheet	300		7.8	1.13	-	0.323
Numerous	Mild steel, hot-rolled		Sheet	300		7.8	0.15	-	0.043
Ferro	Porcelainized Steel	4-mil ground coat	Sheet	300		(b)		(a)	0.06

(a) Cost of 4-mil ground coat, both sides, approximately $0.24
(b) Enamel density alone, 2.7

TABLE 2C

Ceramic Materials

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10^5)		Density (g/cc)	Price		Avg. Cost/ Volume ($/in^3)
				Length-wise	Cross-wise		$/Lb	$/Ft^2	
American Colloid	Bentonite/Paper	-	1/2" Sheet	(a)			-	0.35	0.0048
Resin Coated Sand Company	Foundry sand/phenolic	Casting powder	Powder	(a)		2.8	0.03	-	0.0030
Umaco	Acrylic latex modified Portland cement on plywood base.	Stone Panels	1" Sheet	> 5	(b)	2.5	-	2.00	0.0140
Silibond	Same - 13% Latex	Floor leveling compound	Powder	> 5	(b)	2.5	0.19	-	0.0170
Crossfield	Neoprene-latex elasticized aluminum cement	Floor leveling compound	Powder	> 5	(b)	2.5	-		
Volary	Glass-reinforced gypsum (coated)	1" thick panel	Panel	10 Equivalent		1.7		0.30	0.0021
U.S. Gypsum	Glass-reinforced gypsum (uncoated)	Fabricated, 0.1" thick	Sheet	10 Equivalent		1.7		0.12	0.0083
PPG	Soda-lime glass	Float	Sheet	100		2.24	0.23	-	0.0208

(a) Very low elastic limit; unusably brittle (b) Estimated (c) Water-soluble; unusable

TABLE 2D

Wood Products

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10^5)		Density	Price		Avg. Cost/ Volume ($/in^3)
				Length-wise	Cross-wise		$/Lb	$/Ft^2	
Champion	Plywood	1/4" AC [(a)] 3/8" AC	4' x 8' Sheet	10			- -	0.25 0.34	0.0063
Potlatch	Plywood	1/2" Sheeting [(b)] 1/2" Sanded	4' x 8' Sheet	10			- -	0.22 0.30	0.0042
Plywood Association	Fiberglass/plastic-covered plywood	1/4", with 3/16"FRP 3/8", with 3/16"FRP	Sheet	30			- -	0.50 0.70	Avg. 0.0082
Plywood Association	Kraft paper covered plywood	High-density overlay plywood, 1/4" thick Same, 3/8" thick	Sheet				- -	0.33 0.46	
Roadman	Particle board, Phenolic binder	3/4" thick 3/8" thick	4' x 8' Panel	5		62 lb/ft^3	- -	0.33 0.16	0.0030 0.0029
Roadman	Regular; urea resin binder	3/8" thick	4' x 8' Panel	5		62 lb/ft^3	-	0.19	0.0035
Blandin	Particle Board Segments 1"-1-1/2" large; phenolic binder.	1/4" thick 3/4" thick	4' x 8' Panel 8'x 28' Panel	5			- -	0.13 0.40	0.0036 0.0637
Potlatch	Oriented flake-board; phenolic binder.		Sheet	5					
Masonite	Masonite, Fiber board	No. 1 Siding	7/16" Sheet	3.5		1.5 lb/ft^2	-	0.27	0.0043

(a) A-face with C-backing (suggested for outdoor use).

(b) C-face with D-backing (not weatherable).

TABLE 3-A

Solvent-Based Acrylic Coatings

Manufacturer	Coating	Percent Solids	Specific Gravity of Film (Dry)	T_g, °C	Thermoset; Curing Agent	$/Lb	$/Ft^2/Mil
Rohm & Haas	Acryloid:						
	AT-400	80	1.10		Yes; Melamine	0.26	0.00186
	A-101	40	1.10		No; -	0.49	0.00700
	A-10	30	1.10		No; -	0.65	0.01239
	A-21	30	1.10		No; -	0.42	0.00800
	A-21LV	30	1.10		No; -	0.44	0.00838
	B-44	40	1.10		No; -	0.43	0.00607
	B-48N	45	1.10		No; -	0.54	0.00680
	B-50	45	1.10		No; -	0.48	0.00610
	B-66	50	1.09		No; -	0.49	0.00950
	B-78	45	1.05		No; -	0.60	0.00728
	B-67MT	45	1.05		No; -	0.60	0.00728
	B-72	50	1.15		No; -	0.61	0.00729
	B-82	50	1.16		No; -	0.46	0.00555
	B-84	45	1.10		No; -	0.60	0.00762
	B-99	50	1.10		No; -	0.56	0.00640
	C-10LV	40	1.10		No; -	0.76	0.01086
	F-10	40	1.10		No; -	0.51	0.00729
	NAD-10	40	1.10		No; -	0.68	0.00965
	AT-50	50	1.10		Yes; Self-cure	0.66	0.00755
	AT-51	50	1.10		Yes; Self-cure	0.53	0.00606
	AT-56	50	1.10		Yes; Amine	0.50	0.00572
	AT-70	50	1.10		Yes; Epoxy	0.56	0.00635

...Continued

TABLE 3-A (Continued - 2)

Manufacturer	Coating	Percent Solids	Specific Gravity of Film (Dry)	T_g, °C	Thermoset; Curing Agent	$/Lb	$/Ft^2/Mil
Rohm & Haas	Acryloid:						
	AT-71	50	1.10		Yes; Epoxy	0.51	0.00583
	AT-75	50	1.10		Yes; Epoxy	0.56	0.00635
	AT-63	50	1.10		Yes; -	0.50	0.00572
	AT-64	50	1.10		Yes; -	0.51	0.00583
	Au-608	60	1.10		No; -	0.74	0.00705
	B-7	20	1.10		No; -	0.68	0.01943
	C-10	20	1.10		No; -	0.99	0.02830
	CS-1	83	1.10		No; -	0.93	0.00640
	F-89	60	1.10		No; -	0.65	0.00615
	OL-42	80	1.10		No; -	0.91	0.00650
	RAS-75	86	1.10		No; -	1.06	0.00726
	WR-97	70	1.10		No; -	0.69	0.00564
Conchemco	Acrylic Resin:						
	311-104		1.12				
	311-405		1.12				
	311-121		1.12				
	311-120		1.12				
Goodrich	Carboset:						
	514A	70	1.12			1.04	0.00865
	XL-11	30		55	Yes; Epoxy amine	Experimental	
	XL-19	40		26		Experimental	

...Continued

TABLE 3-A (Continued - 3)

Manufacturer	Coating	Percent Solids	Specific Gravity of Film (Dry)	$T_g, ^oC$	Thermoset; Curing Agent	$/Lb	$/Ft^2/Mil
Ashland Chemical	Aeroset:						
	41-10X60	60	1.13		Yes; Melamine	0.51	0.00494
	41-20-XB50	50	1.14		Yes; Melamine	0.52	0.00610
MR Plastics and Coatings	Mistacote:[a]						
	127-F	20			No; -		
	125-F	19			No; -		

(a) Good adhesion to aluminum

TABLE 3-B

Acrylic Latex Coatings

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T_g (^oC)	Thermoset; Curing Agent	\$/Lb	\$/Ft^2/Mil
B. F. Goodrich	Hycar:							
	2600X83	Anionic	52	1.13	-15	Yes; Self-Cure	0.51	0.00576
	2600X84	Anionic	50	1.14	8	Yes; Self-Cure	0.54	0.00634
	2600X91	Anionic	50	1.13	20		0.54	0.00634
	2600X92	Anionic	50	1.12	-12	Yes; Self-Cure	0.54	0.00623
	2600X94	Anionic	50	1.13			0.56	0.00652
	2600X104	Anionic	50	1.12	-15	Yes; Self-Cure	0.52	0.00605
	2600X106	Anionic	50	1.10	29	Yes; Self-Cure	0.54	0.00617
	2600X112	Anionic	50	1.13	29	Yes; Self-Cure	0.55	0.00646
	2600X120 (a)		50	1.14	-11	Yes; Self-Cure	0.53	0.00622
	260X138	Anionic	50	1.14	25		0.56	0.00658
	2671	Anionic	52	1.13	-11	Yes; Self-Cure	0.58	0.00649
	2679	Anionic	48	1.12	-3	Yes; Self-Cure	0.53	0.00643
	2679X6	Anionic	48	1.10	-3	Yes; Self-Cure	0.58	0.00690
	2600X137		50	1.13	-18	Yes; Self-Cure	0.56	0.00658
	2600X146	Anionic	50	1.13	-55	Yes; Self-Cure	0.99	0.01163
	2600X171	Anionic	48	1.06	45	Yes; Self-Cure	0.56	0.00643
	2600X172	Anionic	50	1.10	33	Yes; Self-Cure	0.57	0.00651
	2600X178		51	1.13			0.58	0.00662
	2600X189	Anionic	51	1.11	-32	Yes; Self-Cure	0.60	0.00679
	2600X205		49	1.13	-43	Yes; Self-Cure	0.68	0.00851
	2600X207		50	1.13	-39		0.68	0.00799
	2600X208		50	1.13			0.56	0.00652

(a) Special

...Continued

TABLE 3-B (Continued - 2)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T_g (^oC)	Thermoset; Curing Agent	$/Lb	$/Ft^2/Mil
B. F. Goodrich	Hycar:							
	2600X210[a]		50	1.14	-20	Yes; Self-Cure	0.56	0.00664
	2600X222	Anionic	49	1.13	-50		0.99	0.01186
	2600X223		50	1.13	-20		0.66	0.00775
	2600X237		50	1.21	76		0.62	0.00780
	2600X238		50	1.13			0.66	0.00775
	2600X255		50	1.13			0.54	0.00628
	2600X256	Anionic	50	1.20	45		0.62	0.00773
Rohm & Haas	Rhoplex:							
	AC-22	Nonionic	44.5	1.15	-27	No; -	0.24	0.00322
	AC-33	Nonionic	46.5	1.15	-27	No; -	0.26	0.00334
	AC-73	Nonionic	46.5	1.15	2	No; -	0.33	0.00479
	B-60A	Nonionic	46.5	1.15	-27	No; -	0.27	0.00344
	AC-234	Nonionic	46.5	1.15	-23	No; -	0.28	0.00353
	AC-61	Anionic	46.5	1.15	-17	No; -	0.31	0.00395
	N-580	Anionic	55	1.15	-85	No; -	0.42	0.00455
	N-619	Anionic	57	1.15	-75	No; -	0.48	0.00503
	HA-4	Nonionic	45	1.15	-62	Yes; -	0.33	0.00438
	B-5	Nonionic	46	1.15	-59	Yes; -	0.54	0.00702
	B-10	Nonionic	46	1.15	-52	Yes; -	0.38	0.00491
	B-15	Nonionic	46	1.15	-49	Yes; -	0.27	0.00354
	LC-40	Anionic	55	1.15	-49	Yes; -	0.37	0.00397
	N-495	Anionic	57	1.15	-48	Yes; -	0.42	0.00440
	K-14	Nonionic	46	1.15	-92	Yes; Self-Cure	0.35	0.00458

(a) Special

...Continued

TABLE 3-B (Continued - 3)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T_g (^oC)	Thermoset; Curing Agent	$/Lb	$/Ft^2/Mil
Rohm & Haas	Rhoplex:							
	K-3	Nonionic	46	1.15	-77	Yes; Self-Cure	0.29	0.00380
	K-87	Nonionic	46	1.15	-63	Yes; Self-Cure	0.35	0.00448
	HA-8	Nonionic	46	1.15	-59	Yes; Self-Cure	0.27	0.00354
	HA-24	Anionic	44.5	1.15	-52	Yes; Self-Cure	0.27	0.00366
	E-32	Nonionic	46	1.15	-47	Yes; Self-Cure	0.27	0.00344
	E-358	Nonionic	60	1.15	-45	Yes; Self-Cure	0.38	0.00376
	E-269	Anionic	46	1.15	-38	Yes; Self-Cure	0.30	0.00393
	RA-90	Nonionic	46	1.15	-33	Yes; Self-Cure	0.30	0.00387
	HA-12	Nonionic	45	1.15	-28	Yes; Self-Cure	0.26	0.00342
	HA-20	Anionic	45.5	1.15	-16	Yes; Self-Cure	0.39	0.00506
	HA-16	Nonionic	46	1.15	-12	Yes; Self-Cure	0.27	0.00354
	TR-520	Nonionic	50	1.15	-53	Yes; Self-Cure	0.30	0.00361
	LC-45	Anionic	65	1.15	-10	Yes; -	0.47	0.00432
	TR-440	Nonionic	46.5	1.15	-59	Yes; Self-Cure	0.35	0.00447
	TR-485	Nonionic/ Anionic	50	1.15	-91	Yes; Self-Cure	0.41	0.00487
	MV-1	Anionic	46	1.15		No; -	0.36	0.00461
	MV-2		46	1.15			0.34	0.00448
	MV-9		45.5	1.15			0.38	0.00499
	MV-17		45	1.15			0.37	0.00485
	N-560		57	1.15			0.45	0.00467
	P-50		43	1.15			0.34	0.00476
	P-64		45.5	1.15			0.30	0.00392
	P-376		50	1.15			0.33	0.00389
	P-491		46	1.15			0.28	0.00364

...Continued

TABLE 3-B (Continued - 4)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T_g (^oC)	Thermoset; Curing Agent	$/Lb	$/Ft^2/Mil
Rohm & Haas	Rhoplex:							
	PR-26		30.5	1.15			0.54	0.01048
	R-47		40	1.15			0.27	0.00403
	TR-96		44.5	1.15			0.37	0.00493
	TR-653		35	1.15			0.26	0.00446
	TR-908		50.5	1.15			0.32	0.00382
	TR-914		50	1.15			0.29	0.00341
	TR-934		44.5	1.15			0.28	0.00369
	WN-80		40	1.15			0.35	0.00527
	B-85	Anionic	38	1.15	55	No; -	0.29	0.00507
	AR-74	Anionic	45	1.15	-4	No; -	0.23	0.00345
	SS-521	Nonionic	50	1.15	10	No; -	0.41	0.00554
	WL-91		41.5	1.15		No; -		
	AC-19		44.5	1.15			0.23	0.00309
	AC-25		46.5	1.15			0.28	0.00353
	AC-64		60.5	1.15			0.35	0.00341
	AC-172		45	1.15			0.37	0.00491
	AC-201	Nonionic	45.6	1.15		Yes; Self-Cure	0.44	0.00570
	AC-235		46.5	1.15			0.29	0.00369
	AC-388		50	1.15			0.29	0.00350
	AC-490	Nonionic	46	1.15		No; -	0.27	0.00351
	AC-507		47	1.15		No; -	0.30	0.00375
	AC-604		46	1.15			0.42	0.00546
	AC-634		46.5	1.15			0.29	0.00366
	AC-635		46.5	1.15			0.30	0.00382
	AC-658		47	1.15			0.39	0.00496

...Continued

TABLE 3-B. (Continued - 5)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T_g (^oC)	Thermoset; Curing Agent	$/Lb	$/Ft^2/Mil
Rohm & Haas	Rhoplex:							
	AC-707		65	1.15			0.37	0.00340
	AC-1084		50	1.15			0.37	0.00442
	B-58		32	1.15			0.54	0.01004
	B-74		38	1.15			0.32	0.00503
	B-88		42.5	1.15			0.30	0.00472
	B-89A	Nonionic	35	1.15		Yes; Self-Cure	0.35	0.00602
	B-413		39	1.15			0.34	0.00535
	B-505	Anionic	40	1.15		Crosslinked	0.31	0.00456
	B-654		40	1.15			0.34	0.00508
	B-832		40	1.15			0.30	0.00441
	B-924		38	1.15			0.23	0.00362
	CA-12		53.5	1.15			0.41	0.00452
	E-330		47	1.15			0.31	0.00394
	LC-67		65	1.15			0.49	0.00451
	MC-76		47	1.15			0.31	0.00394
	Acrysol:							
	WS-12		~30	1.15	~37	Yes; Amines	0.32	0.00628
	WS-24		36	1.15	39	Yes; Amines	0.36	0.00589
	Experimental Emulsion E-15	Anionic	54	1.15	-49	Yes; -		
B. F. Goodrich	Hycar:							
	2600X257		50	1.13			0.55	0.00640
	2671X 20		50	1.13			0.55	0.00646

...Continued

TABLE 3-b (Continued - 6)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T_g (^oC)	Thermoset; Curing Agent	\$/Lb	\$/Ft^2/Mil
B. F. Goodrich	Hycar:							
	2671X22		50	1.13			0.53	0.00623
	2671X23		50	1.13			0.54	0.00634
	2679X22		62	1.13			0.56	0.00530
Staley Chemical Co.	Ubatol:							
	U-3045			1.15				
	U-3050			1.15				
	U-3054		40	1.15	23.5		0.25	0.00037
	U-3101	Anionic	40	1.15			0.26	0.00381
	U-3400	Anionic	40	1.15				
	U-3406		40	1.15			0.20	0.00296
	U-3500			1.15				
	U-3215	Anionic	40	1.15			0.28	0.00411
National Starch	X-Link:							
	2802	Anionic	45	1.19	29	Yes; Self-Cure	0.23	0.00316
	2813	Anionic	45	1.16	-2	Yes; Self-Cure	0.30	0.00402
	2833	Anionic	45	1.13	-29	Yes; Self-Cure	0.28	0.00362
	2873	Anionic	45	1.16	-36	Yes; Self-Cure	0.29	0.00389
Celanese	CL-300	Nonionic	46	1.15				
Johnson Wax	Joncryl:							
	74		49	1.14			0.43	0.00520
	M73 (b)		50				-	-

(b) Custom formulation (not commercial)

...Continued

TABLE 3-B (Continued - 7)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T_g (^oC)	Thermoset; Curing Agent	$/Lb	$/Ft^2/Mil
Polyvinyl Chemical	Neocryl:							
	A601		32	1.12		Yes; Amine	0.39	0.00700
	A604		32	1.12		Yes; Amine	0.44	0.00800
	A620		40	1.12		Yes; Amine	0.36	0.00517
	A621		40	1.15		Yes; Amine	0.36	0.00530
Union Carbide	Ucar:							
	130	Nonionic	58	1.2	43	No; -		
	131	Nonionic	60	1.15	26	No; -		
	150	Nonionic	58	1.2	37	No; -		
	151	Nonionic	60	1.12	24	No; -		
	152	Anionic	58	1.12	-7	Yes; -		
	153	Anionic	55	1.12	-2	Yes; -		
	154	Anionic	60	1.14	0	Yes; -		
	163	Anionic	58	1.12	-5	No; -		
	167	Anionic	63	1.15	23	No; -		
	380	Nonionic	48	1.14	17	No; -		
	865	Anionic	55	1.14	5	No; -		
	872		58	1.12	-7	No; -		
	874		60	1.14	-1	No; -		
	878		61	1.14	10	No; -		
	1248		50					
	4312	Anionic	45	1.1	23	No; -		
	4358	Anionic	45		25	No; -		
	4510	Anionic	43	1.13	44	Yes; -		
	4550	Anionic	45	1.13	39	Yes; -		
	508		53		20			
	4341	Anionic	45.5	1.04	10	No; -		

...Continued

TABLE 3-B (Continued - 8)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T_g (^oC)	Thermoset; Curing Agent	\$/Lb	\$/Ft^2/Mil
Union Carbide	Ucar:							
	165	Anionic/ Nonionic	55	1.15	28	No; -		
	166		55	1.15	22	No; -		
	360		55	1.16	27	No; -		
	365		55	1.15	28	No;		
	366		55	1.15	23	No;		
	366HS		64	1.15	23	No;		
	4150		55	1.15	28	No; -		
	4362		48	1.12	16	No; -		
	5000		55	1.15	5	No; -		

TABLE 4

Glazing Materials on Exposure
in the Weather-Ometer

	Trade Name	Composition	Manufacturer	Sample Thickness Mils
1.	Llumar	Thermoplastic Polyester	Martin Processing	5
2.	Mylar	Thermoplastic Polyester	DuPont	5
3.	45-95-1	Thermoplastic Polyester	National Mettallizing	2
4.	45-95-2	Thermoplastic Polyester	National Mettallizing	2
5.	Ardel 100	Thermoplastic Polyester	Union Carbide	100
6.	Filon 558	Tedlar Coated FRP	Filon Corp.	40
7.	Sun-Lite Premium II	Fiberglass Reinforced Thermoset Polyester	Kalwall	40
8.	Glasteel 500	Fiberglas Reinforced Thermoset Polyester	Glasteel	
9.	Kynar 450	Polyvinylidene Fluoride	Pennwalt	5
10.	PFA 9705	Perfluoroalkoxy	DuPont	2
11.	Halar 500	Ethylene/Chlorotri-fluoroethylene	Allied Chem.	2
12.	FEP-100A	Perfluoroethylene Propylene	DuPont	1
13.	Tedlar 400XRB 160SE	Polyvinyl Fluoride	DuPont	4
14.	Lexan	Polycarbonate	G.E.	40
15.	Tuffak CM-2	Abrasion-Resistant Poly-Carbonate	Rohm & Haas	40
16.	Tenite CAB	Cellulose Acetate	Eastman	35
17.	Plexiglass V811	Polymethyl Methacrylate	Rohm & Haas	40
18.	EVA	Crosslinked Ethylene/Vinyl Acetate Copolymer	DuPont	20

TABLE 5

Housing Materials
Exposed in the Weather-Ometer

1. Super Dorlux Masonite particle board, 0.125"; Masonite Corporation.

2. Pan-L-Board, 0.100"; Mead Corporation.

3. FRP Sheet (glass fiber reinforced polyester), 0.125"; Polyply, Inc.

4. Carbon black filled peroxide crosslinked high/density polyethylene; 0.125"; Springborn Laboratories formulation.

5. Burgess KE clay-filled, peroxide crosslinked high density polyethylene; 0.125"; Springborn formulation.

6. Melamine-M2037 (melamine/formaldehyde copolymer), 0.125"; Fiberite Corporation.

7. Filled phenolic (phenol/formaldehyde copolymer FM 4005), 0.125"; Fiberite Corporation.

8. Dylark 250 (styrene/maleic acid copolymer - glass filled), 0.125"; Arco Chemical Company.

9. Polypropylene structural foam - 30 percent fiberglass; 0.150"; Vantage Products Corporation.

10. Forty percent talc-filled polypropylene; 0.125"; Hercules Corporation.

11. Exterior grade PVC pipe compound 7084 (polyvinyl chloride); 0.125"; B. F. Goodrich Company.

12. IBID "11" but using 85857 compound, 0.125"; B. F. Goodrich.

13. Cellular polyvinyl chloride, 0.125"; B. F. Goodrich.

14. Polyester S660, 0.140"; Fiberite Corporation.

TABLE 6A

Lamination Chart

	Korad 201R	Halar 500	Tedlar 400SG20TR	Tedlar 100BG30UT
Tedlar 400XRB160SE	N / S	N / F	N / N	N / N
Plexiglass V-811	S / S	N / F	N / S	N / S
Crosslinked EVA	F / S	N / M	F / M	M / M
Llumar Polyester	N / S	N / F	N / F	N / F

The top box in each section is lamination by heat alone; the bottom section is with peroxide.

S = Strong Adhesion
M = Moderate Adhesion
F = Failure
N = Not Attempted

TABLE 6B

Lamination Chart

		Korad 201R	Halar 500	Tedlar 400SG20TR	Tedlar 100BG30UT
Tedlar 400XRB160SE	GE	F	F	- N -	- N -
	Dow Corning	F	F	- N -	- N -
Plexiglass V-811	GE	S	F	S	M
	Dow Corning	S	F	F	F
Crosslinked EVA	GE	S	F	F	S
	Dow Corning	S	F	F	S
Llumar	GE	F	F	F	F
	Dow Corning	M	F	F	F

S = Strong Adhesion
M = Moderate Adhesion

F = Failure
N = Not Attempted

TABLE 7A

ETCHING OF PEROXIDE CROSSLINKED
35 MIL EVA (1)

Etching Bath (3)	Time (Min.)	Gloss	Observations
Toluene	6	(2)	Excessive solvent swell.
Toluene (60°C)	6	(2)	Loss of structural integrity (fell apart).
10% KOH, 1% Triton X100 (Soap), 89% Isopropyl Alcohol	6	95%	No development of haze.
85% H_2SO_4 (AQ)	6	74.5%	"Water Spots".
79% H_2SO_4 (AQ) 1.2% $K_2Cr_2O_7$	6	72.5%	Some haze.
Heptane	6	51%	Haze and Mod. surface swell.
Acetone	6	91%	Slight surface swell.
$C\ Cl_4$	6	10%	Much solvent swell and haze
29% NaOH (AQ)	6	88%	No development of haze.
10% NaOH (AQ)	6	91%	No development of haze.
30% N,N-DiMe Formamide, 30% N,N-DiEt Acetamide, 40% Ethylene Glycol	6	108%	Moderate "Water Spotting".
66% H_2SO_4 (AQ) 22% H_3PO_4 (AQ) 7% $K_2Cr_2O_4$	6	101%	Hazy "Water Spotting".
1,1,1-TRI Cl Ethane	6	39%	Hazy surface w/swell.

(1) Ethylene/vinyl acetate copolymer (EVA), Gloss is 112.5%
(2) Cannot obtain gloss from un-flat sample.
(3) In all tables etching baths are at toom temperature, unless specified otherwise.

TABLE 7B

ETCHING OF
ACRYLIC - PLEXIGLASS V-811 (1)

Etching Bath	Time (min.)	Gloss I (2)	Observations (3)	Gloss II (2)
Acetone	6	93.5%	Very slight haze	111.5%
Isopropanol	6	106.5%	Streaky haze	113%
Toluene	6	73%	Slight haze	108%
Et Acetate	6	107%	Very slight haze	113%
Gl. Acetic Acid	6	68.5%	Slight streaks of haze	113%
29% NaOH (AQ)	6	54%	Weaving haze pattern	112%
85% H_2SO_4 (AQ)	6	15.5%	Chalky opaque surface	Surface decomposition
79% H_2SO_4 (AQ) 1% $K_2Cr_2O_4$	6	16.0%	Chalky opaque surface	Surface decomposition
89% Isopropanol 10% KoH 1% Triton X100 (Soap)	6	87%	Slight haze w/"water-spot" streaking	113%
1,1,1-Tri Cl Ethane	6		Feathers (4) Apparent	114%
30% N,N-DiMe Formamide, 30% N,N-DiEt Acetamide, 40% Ethylene Glycol	6		Faint surface scratches and feathers (4)	113%

(1) 123% Gloss for unetched acrylic
(2) Gloss I & II represent gloss reading taken before and after surface cleaning with silicone tissue paper.
(3) These observations are for the uncleaned samples. All surfaces cleared up w/cleaning.
(4) Internal solvent hazed fissures possibly propagated from surface imperfections, by the solvent.

TABLE 7C

ETCHING OF
5 MIL LLUMAR - POLYESTER[1]

Etching Bath	Time (Min.)	Gloss	Observations
Methanol	6	118.5%	Some surface scratches
1,2-DiChloro-Ethylene	6	119%	Light mid-line "water spots"
Isopropanol	6	102.5%	Slight haze
10% KoH 1% Triton X1000 (Soap) 89% Isopropanol	6	117%	A few small "water spots"
Et Acetate	6	118.5%	Clear sample
29% NaOH (AQ)	6	118.5%	A few small "water spots"
85% H_2SO_4 (AQ)	6	99%	Scratched surface w/a few "water spots"
1.2% $K_2Cr_2O_7$ 79% H_2SO_4 (AQ)	6	118%	Clear sample
Gl. Acetic Acid	6	118.5%	Clear sample
1,1,1-Tri Cl Ethane	6	115%	Clear sample
30% N,N-DiMe Formamide, 30% N,N-DiEt-Acetamide, 40% Ethylene Glycol	6	119%	Clear sample

(1) Original Gloss of 119%

TABLE 7D

ETCHING OF
4 MIL PVF - TEDLAR XRB160SE[1]

Etching Bath	Time (Min.)	Gloss	Observations
Acetophenone (100%)	1	24%	Only slight solvent curl
Acetophenone (100%)	2	24%	Difficult to flaten
Acetophenone (100%)	3	24%	Gloss % dependent on position in meter
Acetophenone (100%)	10	19%	Blotchy and crumpled sample
Acetophenone	0	52%	Silky/smooth surface (not shiny)

(1) Original Gloss of 52%

TABLE 7E

OPTICAL PROPERTIES OF
ETCHED MATERIALS

Plastic	Etching	75° Gloss %	Transmission[4] %	Reflectance
EVA[1]	Before After	112.5 37	88 84	6 6
Acrylic V-811(2)	Before After	123 112	93 93	8 6
Llumar[3]	Before After	118 118	83 83	9 8

(1) EVA - etched in cold toluene for 6 minutes. Unreliable reading because solvent swell curled the sample too much to allow it to lay flat.

(2) Acrylic (V-811) - etched in 29% NaOH for 6 minutes.

(3) Llumar Polyester - etched in 29% NaOH for 6 minutes.

(4) Integrated over range of 350-800mμ

*U.S. GOVERNMENT PRINTING OFFICE: 1980-640-189/4214. Region 4.